1. Introduction

1.1 BACKGROUND

The global livestock sector is faced with a three-fold challenge: the need to increase production to meet demand, adapt to a changing and increasingly variable economic and natural environment and, at the same time, improve its environmental performance. While positive effects of grazing systems are locally verified on biodiversity and landscapes, major concerns have been raised about the potential consequences associated with livestock sector growth, including increasing natural resource use and degradation, contribution to global warming, water resource depletion, biodiversity erosion and habitat change. These concerns have resulted in a widespread interest from governments, consumers and industry in the assessment of the environmental performance of livestock production.

The evidence of human-induced climate change (IPCC, 2006) and the important contribution of the livestock sector to total anthropogenic emissions highlight the urgent need to better understand the sources of the livestock sector's greenhouse gas (GHG) emissions and related mitigation options. Starting in 2009, the Animal Production and Health Division of FAO has been engaged in a comprehensive assessment of livestock-related GHG emissions aimed at identifying low-emission development pathways for the livestock sector. The undertaking follows two broad objectives: first, to improve and break down the initial estimates of livestock sector's overall emissions provided in *Livestock's long shadow – Environmental issues and options* (FAO, 2006) and, second, to identify the major available mitigation options along livestock supply chains.

This report presents an update of the *Livestock's long shadow* assessment of GHG emissions from ruminant supply chains. It should be understood as a step in a series of assessments to measure and guide progress regarding the sector's GHG emissions.

1.2 SCOPE OF THIS REPORT

Livestock commodities differ in resource use and emission profile. These variations reflect fundamental differences in the underlying biology and modes of production. The reporting structure reflects this by bringing together species with important shared features concerning their emission profile. This report quantifies the main sources of GHG emissions, and estimates GHG emissions for major ruminant products, predominant ruminant production systems, main world regions and agro-ecological zones (AEZs), and major stages in the supply chains.

The assessment takes a supply chain approach in estimating emissions generated during: (a) the production of inputs for the production process; (b) crop and animal production; and (c) subsequent transport and processing of the outputs into basic products. Given the global scope of the assessment and the complexity of livestock supply chains, several hypotheses and generalizations had to be made to keep data requirements of the assessment manageable. They are documented in the report and their impact on results is analysed. Emissions related to the consumer (the purchase, storage and preparation of food) and food losses that take place at retail and consumer level are not included.

This report addresses a technical audience in private and public organizations, academia and LCA practitioners. Policy-makers and the informed general public will find a comprehensive review of results, methods and the mitigation potential in the livestock sector in an overview report published in parallel to this report (FAO, 2013a).

By providing the most accurate information available on a global scale, this assessment helps to identify priority areas for mitigation and technical options that can reduce GHG emissions from the ruminant sector. It also provides a benchmark against which future trends can be measured.

This report focuses on GHG emissions only; other environmental dimensions, such as water resources, land, biodiversity and nutrients, have not been considered. GHG emissions from the livestock sector cannot be taken as an indicator of environmental sustainability in general. There are important synergies and trade-offs among competing environmental criteria that require fuller assessment.

The base year selected for assessment is 2005. This year was chosen because at the start of the assessment, the available spatial data, and in particular information on the predicted livestock densities, were based on 2005 data.

1.3 THE GLOBAL LIVESTOCK ENVIRONMENTAL ASSESSMENT MODEL

This assessment is based on a newly-developed analytical framework: the Global Livestock Environmental Assessment Model (GLEAM). GLEAM intends to pull together the existing knowledge on production practices and emissions pathways and create a framework for disaggregation and comparison of emissions on a global scale. The model is developed for six animal species (cattle, buffalo, sheep, goats, pigs and chicken) and related edible products. It recognizes two farming systems for ruminant species (mixed and grazing), three for pigs (backyard, intermediate and industrial) and three for chicken (backyard, industrial egg and industrial meat). Overall, this amounts to over 14 000 theoretical supply chains, defined here as unique sets of commodity, farming system, country and climatic zone. The physical area corresponding to each of these sets is further decomposed in cells on a map.

Four publications present the results of this work:

- This technical report addressing the world's cattle, buffalo and small ruminant (sheep and goat) sectors.
- A report addressing the world's pig and chicken (meat and eggs) sectors, published in parallel to this report (FAO, 2013b).
- An earlier technical report published in 2010, addressing the world's dairy sector (FAO, 2010).
- An overview report, summarizing the above at the sector level and providing additional cross-cutting analysis of emissions and mitigation potential, published in parallel to this report (FAO, 2013a).

Since the publication of the FAO report on GHG emissions from the dairy sector (FAO, 2010), GLEAM has been improved to include additional GHG emissions sources such as direct on-farm energy use and indirect energy embodied in farm buildings and equipment. In addition, new data (herd parameters, feed rations) has also been made available, so this report presents an update of the results on dairy production presented in 2010.

1.4 OUTLINE OF THIS REPORT

This report consists of six sections (including this introductory section). Section two starts with a brief introduction to the global ruminant sector describing production systems and their contribution to global ruminant milk and meat production.

Section 3 gives an overview of the approach used in the estimation of GHG emissions in this assessment, providing basic information on the LCA approach. The section presents a description of the functional units used, system boundary, allocation to co-products and sources of GHG emissions. The section also provides an overview of ruminant production system typology applied, the tool (GLEAM) and methods as well as broad information on data sources and management. Detailed description of the approach and methods can be found in the appendices.

The results (total emissions and emission intensities) of this assessment are presented in Section 4 followed by a discussion on the main important sources and drivers of emissions from ruminant species as well as a discussion on uncertainty and assumptions likely to influence the results (Section 5). It also presents the results of a Monte Carlo uncertainty analysis performed in this study.

Section 6 presents the conclusions and recommendations that can be drawn from this work as well as provides direction on areas for improvement.

The appendices in this report provide a detailed description of the GLEAM model, methods applied (on quantifying carbon losses from land-use change, on-farm direct and indirect energy use and post farmgate emissions) and data. The appendices also explore different computation approaches (e.g. for estimating LUC emissions and allocation of emissions to slaughter by-products) presenting their impact on emission intensity.

2. Overview of the global ruminant sector

In this report, the ruminant sector comprises cattle, sheep and goat, and buffalo. The global ruminant population in 2010 was estimated to be 3 612 million (FAOSTAT, 2012), with cattle making up nearly 40 percent, sheep and goat 55 percent, and buffalo the remaining 5 percent. Within the ruminant sector, the cattle sector is by-far the most important: contributing about 64 and 600 million tonnes of meat and milk, respectively; about 79 and 83 percent of total meat and milk production from ruminants. Small ruminant products constitute a relatively small share of globally-produced ruminant meat and milk, about 17 percent and 4 percent, respectively.

Ruminants are mainly reared in either grazing or mixed systems and the relative global importance of mixed systems compared with grazing systems is reflected by the fact that about 73 percent of all ruminants are reared in mixed farming systems. This study estimates that globally about 79 percent of the beef and 85 percent of cattle milk and 70 percent and 68 percent of the small ruminant milk and meat, respectively, is produced in mixed systems. Mixed systems also supply the bulk of products from buffalo; about 97 and 96 percent of milk and meat, respectively. Within these two systems, there is a wide variation in farming practices of which is subject to several factors such as climatic conditions, availability of fodders, market demand, etc.

Agro-ecological conditions are important determinants of the characteristics of ruminant production and estimates of the relative importance of ruminant meat and milk production within the AEZs varies between cattle, buffalo, and small ruminants (see Maps 1, 2, 3, 4 and 5 in Appendix G). In cattle production, temperate zones contribute 50 percent and 38 percent of the milk and beef compared with 21 percent and 33 percent from humid zones and 29 percent and 29 percent from arid zones.

On the other hand, arid zones contribute the bulk of milk and meat production from small ruminants and buffalo; 69 percent and 52 percent of small ruminant milk and meat, and 84 percent and 70 percent of buffalo milk and meat. The humid and temperate zones contribute 12 percent and 18 percent of small ruminant milk and 18 and 29 percent of the meat.

The relative importance of the different species varies enormously – while economic conditions play a key role, factors such as biophysical conditions and cultural values are also important.

Beef production is the most diverse form of all ruminant meat production. It is produced in extremely diverse production systems, ranging from grazing to mixed livestock-crop systems. Beef is either produced in "dedicated" beef herds, where beef is the only main product, or as a co-product from dairy production, i.e. surplus calves from dairy herds are raised for beef and culled cows are used for meat.

Specialized beef production units may take many forms: breeding and growing beef enterprises, breeding and finishing, growing and finishing on pasture or in feedlots, etc. Such forms of production are usually located in the industrialized world regions and Latin America. However, in many parts of the world, particularly in the developing regions, this distinction between dairy and specialized beef production is subtle especially where cattle are considered multifunctional producing both milk and meat as well as other valuable non-edible products and services such as manure, hides and skin, and are used for draught power.

Despite their small contribution to global milk and meat output, sheep and goat farming plays a larger role in some specific economies. In many marginal rural areas, it plays a significant socio-economic role. An important attribute of small ruminants is that they are able to thrive and produce on unfavourable land and are generally suited to harsh climatic conditions where cattle would perform poorly. Sheep and goats are better converters of low-quality fibrous feed into meat and milk due to their better digestive ability to utilize poor quality roughages. In this regard, about 56 percent of the world's small ruminants are located in arid zones and 27 percent and 21 percent in the temperate and humid zones, respectively. However, these animals also adapt very easily to intensive production systems and can produce meat and milk efficiently.

Milk and meat products from sheep and goats have two purposes: they are used for subsistence at household level or are sold as niche products. Meat and milk from sheep is usually obtained from high yielding animals kept under intensive conditions e.g. dairy intensive systems in the Mediterranean region, lamb production in New Zealand and Australia. In Northern Europe and Oceania (particularly New Zealand), sheep are kept mainly for meat production while in the Mediterranean region almost all sheep and goats belong to dairy breeds where milk is the main output of production and meat considered as a by-product.

Similar to other ruminant species, systems of buffalo production vary widely through the different regions of the world and are determined by several interacting factors that include climate (tropical or temperate, humid or arid), location (rural, peri-urban or urban), cropping systems (rain-fed or irrigated, annual or perennial crops), type of operation (small or large farm, subsistence or commercial), and primary purpose for buffalo production and/or management (milk, meat, draught power or mixed).

In South Asia, North Africa and the Near East, buffalo are mainly kept for milk and meat production. In East & Southeast Asia, draught power and meat are important, while in Europe, buffalo are kept on large commercial farms under modern intensive systems for milk and meat production (Perera, 2011).

Buffalo provide milk, meat, hides and draught power. Among the different products obtained from buffalo, meat and hides are more important, although buffalo play an important role in milk production in Asian countries and few countries in the Mediterranean region. Global milk production is concentrated in two countries, India and Pakistan, which together account for 92 percent of the world's total milk production. Buffalo have an inherent ability to produce milk of high fat contents (ranging from 6 to 8.5 percent) and, because of this, buffalo milk is preferred over cow milk in some regions of the world such as South Asia. In 2010, about 98 percent of the global buffalo meat production was produced in South, East and Southeast Asia with the bulk contributed by India and Pakistan. This is easily explained by the fact that the two countries have 73 percent of the global buffalo population. Besides edible products, ruminants also produce a host of non-edible products such as manure, hides and skin, and natural fibre (wool, cashmere and mohair). While farm mechanization has resulted in significant reduction in the use of animals for draught power, farmers in many parts of the world still rely on cattle and buffalo as a source of draught power.

3. Methods

3.1 CHOICE OF LIFE CYCLE ASSESSMENT (LCA)

The use of Life Cycle Assessment (LCA) to assess food production is becoming increasingly common. This trend is driven by the need of policy-makers, producers and consumers for reliable and comprehensive environmental information to identify environmentally and economically sustainable agricultural products and practices.

The LCA approach, which is defined in ISO standards 14040 and 14044 (ISO, 2006), is now widely accepted in agriculture and other industries as a method for evaluating the environmental impact of production, and for identifying the resource and emission-intensive processes within a product's life cycle. The main strength of LCA lies in its ability to provide a holistic assessment of production processes in terms of resource use and environmental impacts, as well as to consider multiple parameters (ISO, 2006).

LCA also provides a framework to broadly identify effective approaches to reduce environmental burdens and is recognized for its capacity to evaluate the effect that changes within a production process may have on the overall life-cycle balance of environmental burdens. This enables the identification and exclusion of measures that simply shift environmental problems from one phase of the life cycle to another.

However, LCA also presents significant challenges, particularly when applied to agriculture. First, the data-intensive nature of the method places limitations on the comprehensive assessment of complex food chains and biological processes. Limited data availability can force the practitioner to make simplifications, which can lead to losses of accuracy.

A second difficulty lies in the fact that methodological choices and assumptions such as system boundary delineation, functional units, and allocation techniques may be subjective and affect the results. These complications call for a thorough sensitivity analysis.

3.2 GENERAL PRINCIPLES OF LCA

The LCA method was originally applied to analyse industrial process chains, but is increasingly being used to assess the environmental impacts of agriculture. It involves the systemic analysis of production systems to account for all inputs and outputs associated with a specific product within a defined system boundary. The system boundary largely depends on the goal of the study.

The reference unit that denotes the useful output of the production system is known as the functional unit, and it has a defined quantity and quality. The functional unit can be based on a defined quantity, such as 1 kg of product, or it may be based on an attribute of a product or process, such as 1 kg of fat and protein corrected milk (FPCM) or 1 kg of carcass weight (CW).

The application of LCA to agricultural systems is often complicated by the multiple-output nature of production, because major products are usually accompanied by the joint production of by-products. This requires appropriate partitioning of environmental impacts to each product from the system according to an allocation rule, which may be based on different criteria such as economic value, mass balances, product properties, etc.

3.3 USE OF LCA IN THIS ASSESSMENT

In the last five years, an increasing number of LCA studies have been carried out for livestock production, mostly in Organisation for Economic Cooperation and Development (OECD) countries (Leip *et al*., 2010; Ledgard *et al.*, 2011; Beauchemin *et al*., 2010; de Vries and de Boer, 2010; Verge *et al*., 2008; Foley *et al*., 2011). Although LCA methods are well defined, the studies vary considerably in their level of detail, their definition of system boundaries, the emission factors (EFs) they use, and other technical aspects such as the allocation techniques and functional units they employ.

This assessment sets out to perform a complete LCA for the global livestock sector, using consistent calculation methods, modelling approaches, data and parameters for each production system within the sector. In contrast to previous LCA studies carried out for the livestock sector, which have primarily concentrated on either farm level or the national level emissions in OECD countries, this study is global in scope and includes both developed and developing countries.

As a consequence of its global scope, the approach developed for this study has had to overcome onerous data requirements by relying on some simplifications that result in a loss of accuracy, particularly for systems at lower levels of aggregation.

This assessment follows the attributional approach, which estimates the environmental burden of the existing situation under current production and market conditions, and allocates impacts to the various co-products of the production system. This differs from the consequential LCA approach, which considers potential consequences of changes in production, and relies on a system expansion analysis to allocate impacts of co-products (Thomassen *et al*., 2008).

The current assessment is based on the methodology for LCA, as specified in the following documents:

- ISO, 2006. *Environmental management – Life Cycle Assessment- Requirements and guidelines* - BS EN ISO 14044.
- British Standards Institute PAS 2050; 2008. Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (BSI, 2008).

3.3.1 Functional unit

Ruminant production systems produce a mix of goods and services:

- Edible products: meat and milk.
- Non-edible products and services including natural fibre (wool, cashmere, mohair), draught power, hides and skin, manure and capital.

In this assessment, the functional units used to report GHG emissions for meat are expressed as a kg of carbon dioxide equivalents (CO_2-eq) per kg of carcass weight (CW) and emissions from milk are reported in CO_2-eq per kg of FPCM. FPCM is a method used to standardize milk produced in different systems with varying qualities. Appendix A provides details of the equations used in the standardization of milk from ruminants.

3.3.2 System boundary

The assessment encompassed the entire livestock production chain, from feed production through to the final processing of product, including transport to the retail distribution point (see Figure 1).

The cradle to retail system boundary is split into two subsystems:

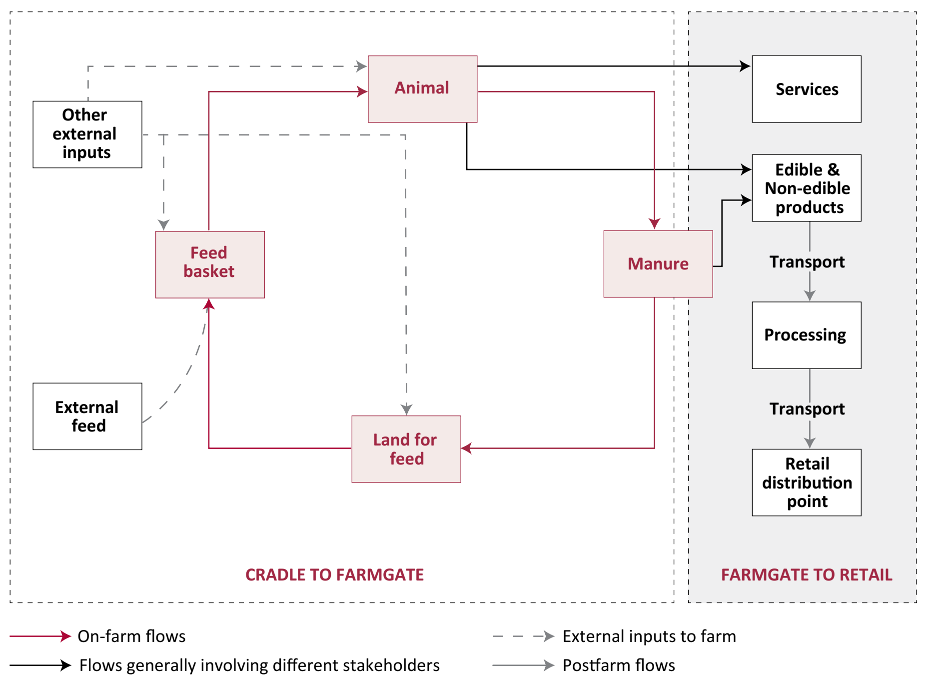
- *Cradle to farmgate* includes all upstream processes in livestock production up to the farmgate where the animals or products leave the farm, i.e. production of farm inputs and on-farm production activities.
- *Farmgate to retail* includes transport of animals and product (milk) to processing plants (dairies and slaughter plants) or directly to market, processing into primary products, refrigeration during transport and processing, production of packaging material, and transport to the retail distributor.

All aspects related to the final consumption of milk and meat products (i.e. consumer transport to purchase product, food storage and preparation, food waste and waste handling of packaging) lie outside the defined system, and are thus excluded from this assessment.

To calculate GHG emissions from cradle to farmgate, a simplified description of livestock production systems (derived from Oenema *et al.*, 2005; Schils *et al.*, 2007; Del Prado and Scholefield, 2008) was developed (Figure 1).

Livestock production is complex, with a number of interacting processes that include crop and pasture production, manure handling, feed processing and transport, animal raising and management, etc. This requires modelling the flow of all

Figure 1.
System boundary as defined for this assessment



Source: Authors.

Table 1. Sources of GHG emissions included and excluded in this assessment

Food chain	Activity	GHG	Included	Excluded
Upstream	Feed production	N_2O	Direct and indirect N_2O from: • Application of synthetic N • Application of manure • Deposition of manure on pasture, ranges • Crop residue management	• N_2O losses related to changes in C stocks • Biomass burning • Biological fixation • Emissions from non-N fertilizers and lime
		CO_2	• Energy use in field operations • Energy use feed transport and processing • Fertilizer manufacture • Feed blending • Land-use change related to deforestation soybean and pasture expansion	• Changes in carbon stocks from land use under constant management practices
	Non-feed production	CO_2	• Indirect (embedded) energy related to the manufacture of on-farm buildings and equipment	• Production of cleaning agents, antibiotics and pharmaceuticals
Animal production unit	Livestock production	CH_4	• Enteric fermentation • Manure management	
		N_2O	• Direct and indirect N_2O from manure management	
		CO_2	• Direct on-farm energy use for milking, cooling, ventilation and heating	
Downstream	Post farmgate	CO_2; CH_4; HFCs	• Transport of live animals and product to slaughter and processing plant • Transport of processed product to retail point • Refrigeration during transport and processing • Primary processing of meat into carcasses or meat cuts and raw milk and dairy products • GHGs related to leakage of refrigerants during transportation • Manufacture of packaging	• On-site waste water treatment • Emissions from animal waste or avoided emissions from on-site energy generation from waste • Emissions related to slaughter by-products e.g. rendering material, offal, hides and skin • Retail and post-retail energy use • Waste disposal at retail and post-retail stages

Source: Authors.

products through internal chains on the farm and also allowing for imports and exports from the farm. The model therefore provides a means of integrating all these processes and linking all components in a manner that adequately captures major interactions among biological and physical processes. The flows are represented as directional lines between compartments in the system.

- "*Land for feed*" is the land used for feed production, on the farm itself or within the vicinity of production site (with negligible emissions related to the transport of feed to the animal rearing site).
- "*External feed*" originates from off-site production and includes by-products from the food industry and feed crops produced and transported over longer distances, e.g. soybeans; in most situations, the external feed is concentrate feed.
- "*Manure*" is shown partly outside the 'cradle-to-farmgate' system boundary in order to illustrate situations where manure is used as a fertilizer on food crops, either on- or off-farm, or where manure is used as fuel.
- "*Other external inputs*" refers to the inputs into production such as energy, fertilizer, pesticides, on-farm machinery, etc.

The connection of the four compartments shown in Figure 1 requires the development of specific models (see Appendix A) and attribution techniques (see Section 3.6 and Appendix A) for the allocation of emissions among different processes, uses and outputs. These compartments not only represent different activities in the production process such as animal production, feed production, manure management, etc., but also define the inter-linkages among production processes such as the link between animal performance (genetics, management), animal feed requirements (energy and protein requirements) and the production of outputs such as edible and non-edible products and services, and emissions.

3.3.3 Sources of GHG emissions

This study focuses on emissions of the three major GHGs associated with animal food chains – methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) – as well as GHGs related to refrigerants. The following emission sources were included and further grouped into pre- and post farmgate sources, and a number of potential GHG emissions and sinks were excluded from the analysis (Table 1).

Table 1 also illustrates a number of processes and activities in the livestock food chain that have been excluded due to:

- lack of global databases, e.g. on the production of co-products at slaughterhouse, post retail emissions, etc.;
- lack of methodology or consensus on quantification approach, e.g. changes in soil carbon stocks from LU; and
- limited contribution of the processes to the carbon footprint, e.g. use of production of cleaning agents, antibiotics and pharmaceuticals.

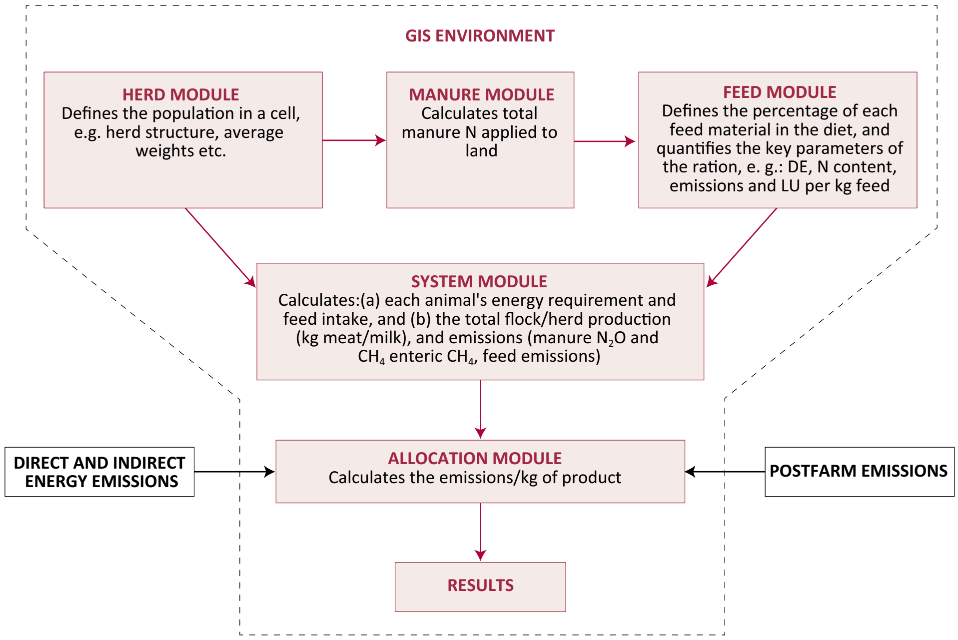
Emission categories and a description of the emissions included in each category are presented in Table 2.

Table 2. Description of emission categories used in this assessment

Category		Description
Feed N_2O		Direct and indirect N_2O emissions from manure deposited on pasture Direct and indirect N_2O emissions from organic and synthetic N applied to crops and pasture
Feed CO_2	blending and transport	CO_2 arising from the production and transportation of compound feed
	fertilizer production	CO_2 from energy use during the manufacture of urea and ammonium nitrate (and small amounts of N_2O)
	processing and transport	CO_2 from energy use during crop processing (e.g. oil extraction) and transportation by land and (in some cases) sea
	field operations	CO_2 arising from the use of energy for field operations (tillage, fertilizer application). Includes emissions arising during both fuel production and use.
Feed LUC CO_2		CO_2 from LUC associated with soybean cultivation and pasture expansion
Indirect (embedded) energy CO_2		CO_2 arising from energy use during the production of the materials used to construct farm buildings and equipment
Manure N_2O		Direct and indirect N_2O emissions arising during manure storage prior to application to land
Manure CH_4		CH_4 emissions arising during manure storage prior to application to land
Enteric CH_4		CH_4 arising from enteric fermentation
Direct energy CO_2		CO_2 arising from energy use on-farm for heating, ventilation etc.
Post farmgate		Energy use in processing and transport

Source: Authors.

Figure 2.
Overview of the GLEAM modules and computation flows



Source: Authors.

3.4 OVERVIEW OF CALCULATION METHOD

A specific model and related databases were developed to carry out this assessment. The Global Livestock Environmental Accounting model (GLEAM) was designed to represent processes and activities from the production of inputs into the production process to the farmgate, the point at which products and animals leave the farm. It consists of five main modules: *herd module, manure module, feed basket module, system module and allocation module* and two additional modules for the calculation of direct and indirect on-farm energy and post farmgate emissions (Figure 2). Appendix A provides a detailed explanation of GLEAM.

3.4.1 Spatial variation and the use of Geographic Information System

A challenge faced in conventional LCA modelling is the complexity and variation in biophysical characteristics (such as soil and climate) as well as production processes. Data on farming activities and farming system parameters were collected at different levels of aggregation: production system, country level, AEZs, or a combination thereof (e.g. information on manure storage in developing countries was available for a combination of production systems and AEZs). Additional data, such as livestock numbers, pasture and availability of feedstuff was available in the form of Geographical Information System (GIS) grids (raster layers), with a spatial resolution not coarser than 5 arc minutes (ca. 10 km x 10 km at the equator). For the outputs of GLEAM, a spatial resolution of 3 arc minutes (ca. 5 km x 5 km at the equator) was used.

GIS can store observed data for specific locations (e.g. soil types, climate factors), can model new information from these data and can also calculate regional summaries such as total area, emissions, etc. GIS was used to analyse spatially varied data (such as crop yields, livestock species distribution), generate location-specific input data required for LCA modelling (e.g. define the typology of livestock production systems, and calculate location-specific feed-crop availability, classification of dominant soil types in forested areas and location-specific temperature to estimate EFs such as CH_4 conversion factors for MMS) and store numerical model input and output data in a GIS database.

The use of GIS allowed the incorporation of spatial heterogeneity into the modelling process which brought with it the benefit of enhancing the reliability of data used as well as results. Furthermore, it produced a more spatially accurate inventory of emissions, particularly CH_4 emissions which are modelled based on animal cohorts and feed intake. In this way, emissions were estimated at any location of the globe, based on available information, and then aggregated along the desired category, e.g. farming systems, country group, commodity and animal species. This assessment thus demonstrates the potential of coupling GIS technology with LCA for assessing GHG emissions from the livestock food chain.

3.4.2 Emission factors

The GHG EFs applied for the various emission sources in this study are specified in Appendix B of this report. A combination of IPCC (2006) Tier 1 and Tier 2 approaches and EFs were used in the estimation of emissions.

Despite the existence of country-specific EFs, the study applied the same approach to all countries. The use of a unified approach was preferred for the assessment, to ensure consistency and comparability of results across regions and farming systems.

IPCC Tier 2 approaches were used in the characterization of livestock population, to calculate emissions related to enteric fermentation as well as manure management and storage. The Tier 1 method was used where data was generally lacking, e.g. estimation of carbon stocks from LUC and N_2O emissions from feed production.

Global Warming Potentials (GWPs) with a time horizon of 100 years based on the 4th Assessment Report of the IPCC (IPCC, 2007) were used to convert N_2O and CH_4 to CO_2-eq terms. Consequently, GWP of 25 and 298 were used for CH_4 and N_2O, respectively.

3.4.3 Land use and land-use change

Assessment of changes in carbon stocks for agricultural land remaining in the same land use category requires dynamic process models and/or detailed inventory measurements. According to IPCC (2006), these models should be able to represent all relevant management practices and their driving variables compatible with available country data. Their validity should also be reported in empirical assessments. As no models satisfy these criteria and are validated on a global scale, this analysis doesn't incorporate C stock changes under constant land use. Nevertheless, a discussion on the effect of this simplification is provided in Appendix C, in particular about the role of grasslands in C sequestration.

Land-use change (LUC) is a highly complex process. It results from the interaction of drivers which may be direct or indirect[3] and which can involve numerous transitions, such as clearing, grazing, cultivation, abandonment and secondary forest re-growth. The debate surrounding the key drivers of deforestation is a continuing one and the causal links (direct and indirect) are both complex and unclear.

In this assessment, LUC considered are the transformation of forest to cropland and of forest to pasture. The former focuses on deforestation associated with soybean production in Brazil and Argentina. This choice results from the use of 2005 as year of reference and from the following observations of trends in LU transitions and crop expansions:

- In the period 1990-2006,[4] which is used as the reference time period in this study, the main global cropland expansions were for maize and soybean production;
- Maize and soybean expansion occurred in different regions of the world but only in Latin America can it be linked to a decrease in forest area during the same period; and
- Within Latin America, Brazil and Argentina account for 91 percent of the total soybean area. Over the period 1990–2006, 90 percent of the soybean area expansion in Latin America took place in these two countries.

LUC emissions were then attributed to only those countries supplied by Brazil and Argentina for soybean and soybean cake, proportionally to the share on imports from these two countries in their soybean supply. This study also provides an analysis of sensitivity to these assumptions, in particular on the reference time period, the expansion of soybean at the expense of other land types including forestland (arable and perennial cropland and grassland) and the assumption that all traded soybean and soybean cake is associated with LUC (see Appendix C).

The second LU transformation focuses on deforestation associated with pasture expansion in Latin America. This choice results from the observation that, during the period 1990-2006, significant pasture expansions and simultaneous forest area decrease occurred in Latin America and Africa. However, due to the lack of reliable data and information, it is difficult to draw conclusions on the land-use conversion trends in Africa.

LUC emissions associated with the expansion of pasture into forest areas in Latin America are attributed to beef production in those countries in which the conversion occurred. Appendix C provides an elaboration of the approach applied.

3.5 DATA SOURCES AND MANAGEMENT

The availability of data varies considerably within and among key parameters. In general, the OECD countries possess detailed statistics, supported by several scientific and technical publications. In contrast, there is a severe paucity of data in non-OECD countries. Where detailed and accurate data are available, they are often outdated and/or lack supporting metadata. Appendix B presents some of the data utilized in this assessment.

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3 Direct drivers include conversion of forest areas for plantation crops or cattle ranching, rural settlements, mining and logging. Indirect drivers include subsidies for agribusiness, investment in infrastructure, land tenure issues, absence of adequate surveillance by the government and demand for forest products, such as timber.

4 1990 is chosen as the initial year because it is the most recent available year with a consistent forest dataset from the FAOSTAT database. This practically discounts 4 years of LUC related emissions, compared to the 20-year timeframe recommended by IPCC (IPCC, 2006).

Table 3. Overview of the data sourced for the preparation of this assessment

Data groups	Data collection approach and sources
Herd (animal parameters)	Literature reviews, reports and surveys (see Appendix B)
Manure management	Literature reviews and reports (see Appendix B)
Feed basket	Literature reviews, reports; IFPRI (GIS based data)
LCI feed components	Literature reviews, reports; IFPRI (GIS based data), LCI databases Sweden and the Netherlands
Yield	Literature reviews and FAOSTAT
Non-edible products	Literature reviews and reports, FAOSTAT
Carbon stocks	Use of model based on Gross Primary Production (GPP)
Deforestation	FAO Forestry statistics, IPCC guidelines, literature and own calculations (see Appendix C)
Animal population characterization	Herd layer data, FAOSTAT and FAO Gridded Livestock of the World
Capital goods	Ecoinvent database and literature reviews

Source: Authors.

During the process of data collection, gaps initially encountered were addressed, to the extent possible, by extensive research of databases, literature sources and expert opinion. Assumptions were made when data could not be obtained. Data collection involved a combination of research, direct communication with experts, and access to public and commercially available life cycle inventory (LCI) packages such as Ecoinvent. The study's main data sources included:

- Gridded Livestock of the World (FAO, 2007).
- National Inventory Reports of Annex I countries (UNFCCC, 2009a).
- National Communications of non-Annex I countries (UNFCCC, 2009b).
- Geo-referenced databases on crop production from the International Food Policy Research Institute (You *et al.*, 2010).
- Above-ground net primary production (NPP) (Haberl *et al.*, 2007)
- Life Cycle Inventory (LCI) data from the Swedish Institute for Food and Biotechnology (Flysjö *et al.*, 2008), and Wageningen University, the Netherlands (I. de Boer, personal communication).
- Reports from the CGIAR research institutes.
- Statistics from FAO (FAOSTAT, 2009).
- Peer-reviewed journals.

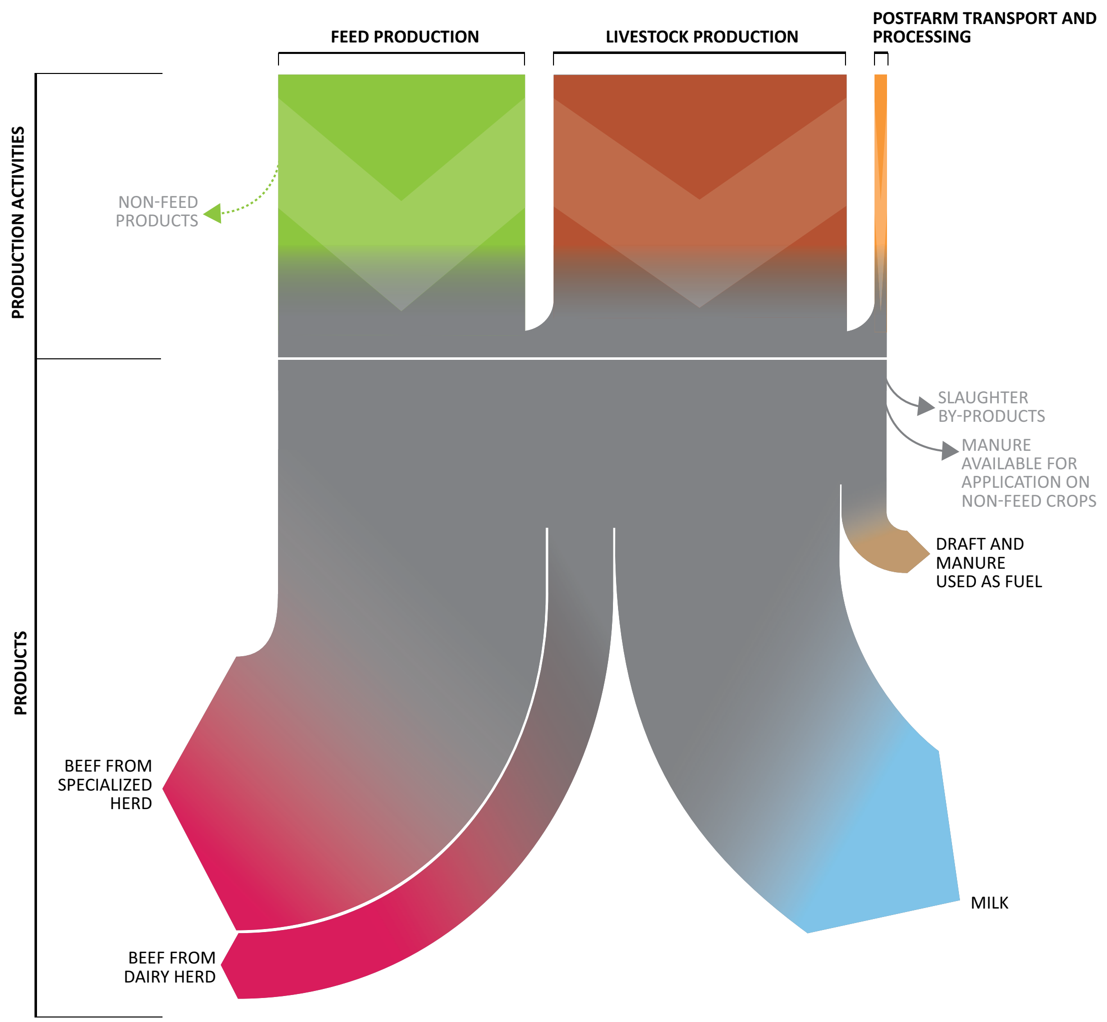
The data have been organized into data groups or "basic data layers". Table 3 summarizes the data collection approach and sources for each main data group.

Further detail on data and data sources is given in Appendix B.

3.6 ALLOCATION OF EMISSIONS BETWEEN PRODUCTS, BY-PRODUCTS AND SERVICES

Livestock produce a mix of goods and services that cannot be disaggregated easily into individual processes. For example, a dairy cow produces milk, manure, draught power and capital services, and eventually meat when it is slaughtered. Given that multiple products are produced from each of the ruminant species, the environmental burden associated with production needs to be allocated for each of the products. In LCA, specific techniques are required to attribute relative shares of

Figure 3.
An illustration of production activities and partitioning of total emissions to products and services from cattle



Source: Authors.

GHG emissions to each of these goods and services. The ISO recommends avoiding allocation by dividing the main process into sub-processes, or by expanding the product system to include additional functions related to the co-products (ISO, 2006). In situations where allocation cannot be avoided (as is often the case in biological processes such as livestock production), GHG emissions can be allocated on the basis of causal and physical relationships.

Where physical relationships alone cannot be established or used as a basis for allocation, emissions should be allocated in a way which reflects other fundamental relationships. In the latter case, the most commonly used approach is economic allocation which, in the context of jointly produced products, allocates emissions to each product according to its share of the products' combined economic value. Other indexes, such as weight or protein content, can also be used (Cederberg and

Figure 4.
Classification of ruminant production systems used in the assessment

HERD TYPE	SYSTEM	CLIMATE	COUNTRY
Dairy herd *(producing milk and meat)*	Mixed[1] Grassland based[2]	Arid Humid Temperate/ tropical highlands	A B ...
Pure meat herd *(producing only meat)*	Mixed[1] Grassland based[2]	Arid Humid Temperate/ tropical highlands	A B ...

[1] Grassland-based livestock systems: Livestock production systems in which more than 10 percent of the dry matter fed to animals is farm-produced and in which annual average stocking rates are less than ten livestock units per hectare of agricultural land (FAO, 1996).
[2] Mixed farming systems: Livestock production systems in which more than 10 percent of the dry matter fed to livestock comes from crop by-products and/or stubble or more than 10 percent of the value of production comes from non-livestock farming activities (FAO, 1996).
Source: Authors.

Stadig, 2003). The allocation techniques used in this assessment to apportion emissions to products and services produced by ruminant systems are summarized below:

- Edible products (e.g. meat and milk): allocation based on protein content.
- Edible and non-edible products (e.g. milk, meat and fibre): allocation based on economic value of outputs.
- Slaughter by-products: no allocation is performed in this assessment. Appendix F explores the impact of allocating emissions to slaughter by-products.
- Manure: allocation based on sub-division of production process.
  - manure storage: emissions from manure management systems (MMS) allocated to livestock sector;
  - manure applied to feed: emissions allocated to livestock sector based on mass harvested and relative economic value;
  - manure applied to non-feed: no allocation to livestock sector; and
  - manure used for fuel: Emissions are deducted from the overall emissions and therefore are not allocation to livestock sector.
- Capital function: no allocation is performed in this assessment.
- Services (e.g. animal draught power): biophysical allocation based on extra-life time gross energy requirements for labour and emissions are deducted from the overall livestock emissions.

A detailed account of the application of the allocation technique is provided in Appendix A. Figure 3 illustrates flows of outputs from the cattle sector.

3.7 PRODUCTION SYSTEM TYPOLOGY

This assessment estimates emissions at global, regional and farming system levels. A farming system typology was thus adapted to provide a framework for examining GHG emission from different dairy farming systems. This typology is based on the classification principles set out by FAO (1996), namely, the feed-base and the agro-ecological conditions of production systems (Figure 4).

The following three AEZs were used:

- *"temperate": temperate regions*, where for at least one or two months a year the temperature falls below 5 °C; and *tropical highlands*, where the daily mean temperature in the growing season ranges from 5 to 20 °C.;
- *"arid": arid and semi-arid tropics and subtropics*, with a growing period of less than 75 days and 75-180 days, respectively; and
- *"humid": humid tropics and sub-humid tropics* where the length of the growing period ranges from 181-270 days or exceeds 271 days, respectively.

The widely-used classification approach developed by FAO (1996) that was used here has a number of advantages: it allows researchers to use the multiple databases developed using this structure [e.g. geo-referenced data on animal numbers in each livestock production system (LPS)]; it provides a conceptual framework to make estimates where data are lacking; and it enhances the compatibility of this work with other analyses using similar classification schemes.